Impact of Bandwidth on Contrast Sensitive Structures for low k1 Lithography

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ABSTRACT

Double-patterning ArF immersion lithography continues to advance the patterning resolution and overlay requirements and has enabled the continuation of semiconductor bit-scaling. Over the years Lithography Engineers continue to focus on CD control, overlay and process capability to meet current node requirements for yield and device performance. Reducing or eliminating variability in any process will have significant impact, but the sources of variability in any lithography process are many. The goal from the light source manufacturer is to further enable capability and reduce variation through a number of parameters. [1, 2, 3, 4]

Recent improvements in bandwidth control have been realized in the XLR platform with Cymer's DynaPulse™ control technology. This reduction in bandwidth variation could translate in the further reduction of CD variation in device structures. The Authors will discuss the impact that these improvements in bandwidth control have on advanced lithography applications. This can translate to improved CD control and higher wafer yields. A simulation study investigates the impact of bandwidth on contrast sensitive device layers such as contacts and 1x metal layers. Furthermore, the Authors will discuss the impact on process window through pitch and the overlapping process window through pitch that has been investigated. These improvements will be further quantified by the analysis of statistical bandwidth variation and the impact on CD.

1. INTRODUCTION

Further improvements in bandwidth variation in the XLR platform has been realized with Cymer's DynaPulse™ bandwidth control technology. This reduction in bandwidth variation could translate in the further reduction of CD variation in device structures. The Authors will discuss the impact that these improvements in bandwidth control have on advanced lithography applications. This can translate to improved CD control and higher wafer yields. This study investigates the impact of bandwidth on contrast sensitive device layers. These improvements will be further quantified by the analysis of statistical bandwidth variation and the impact on CD.

2. RECENT IMPROVEMENTS IN BANDWIDTH CONTROL

2.1 Experimental Conditions

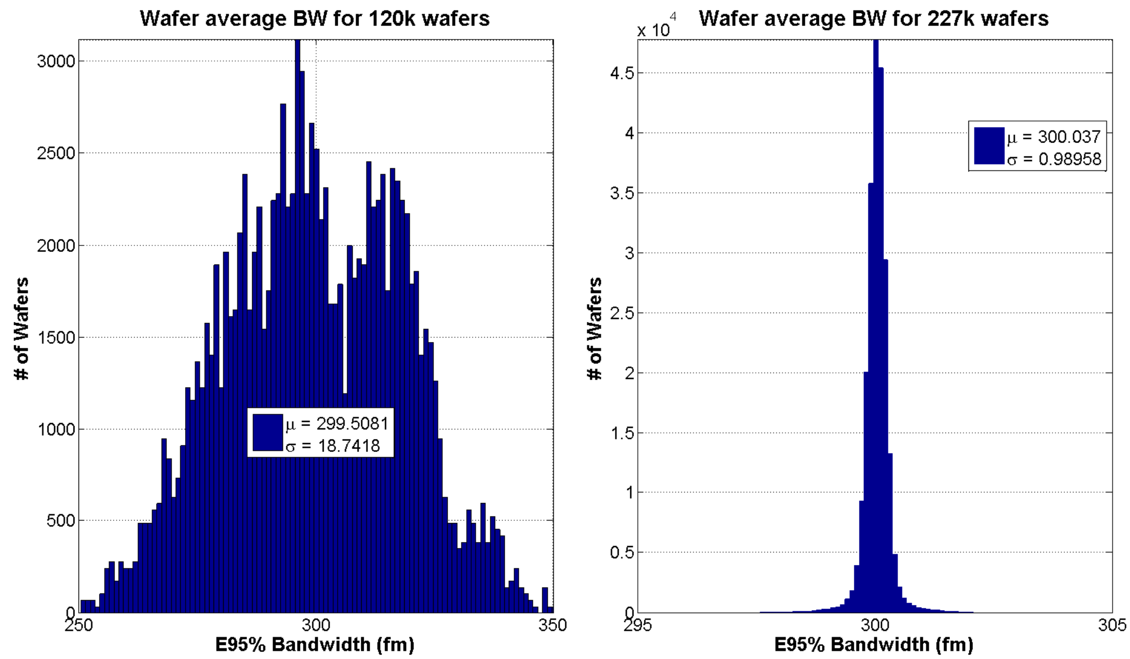

Figure 1: On wafer response to E95 modulation per field
(plot on left-legacy controller, plot on right ETC controller)

Cymer has previously discussed the capability the ETC controller demonstrating that bandwidth stability was dramatically improved over the previous generation of bandwidth controllers.[5] When ETC is enabled on an XLR system, the controller is able to maintain the bandwidth mean to within ± 5fm of the target as shown in Figure 1. The left side of the plot is the legacy controller bandwidth performance and on the right the current DynaPulse bandwidth controller demonstrating this dramatic improvement.

3. THE VARIABILITY WINDOW

3.1 Methodology

The Authors have developed a test methodology to determine the impact of bandwidth variability through the known dose and focus variability that exists in the scanner. This "variability window" demonstrates the CD variability that could exist within the test case for the baseline controller and Baseline vs. DynaPulse™ technology.

For this study, simulations are performed with HyperLith v7 from Panoramic Technologies. The chosen imaging conditions are 1.35NA using cQuad illumination with an outer setting of 0.87 and inner setting of 0.72. No aberrations or Jones matrix was included and the mask test site provided by Panoramic, to 90nm pitch ground rules with simple OPC applied. The mask is a standard 6% attenuated PSM calculated using Kirchoff's approximation. An LPM positive resist model was used with a simple calibration to existing 45nm line and space imaging. The bandwidth variation for this study is 300fm (+75/-25fm -baseline condition) and 300fm (+/-5fm – DynaPulse condition). Dose variation of +/- 0.45% and a focus variation of +/-14nm used, based on existing known scanner specifications.

3.2 Test Site

Figure 2 is the flow of the 90nm pitch test site used in this study. The Authors have applied simple OPC based on the imaging and ground rules using Panoramic Technologies. The calculated aerial image and imaging in positive tone photoresist is shown. The image at the bottom of the figure points to the three specific locations. This is illustrated in the figure below.

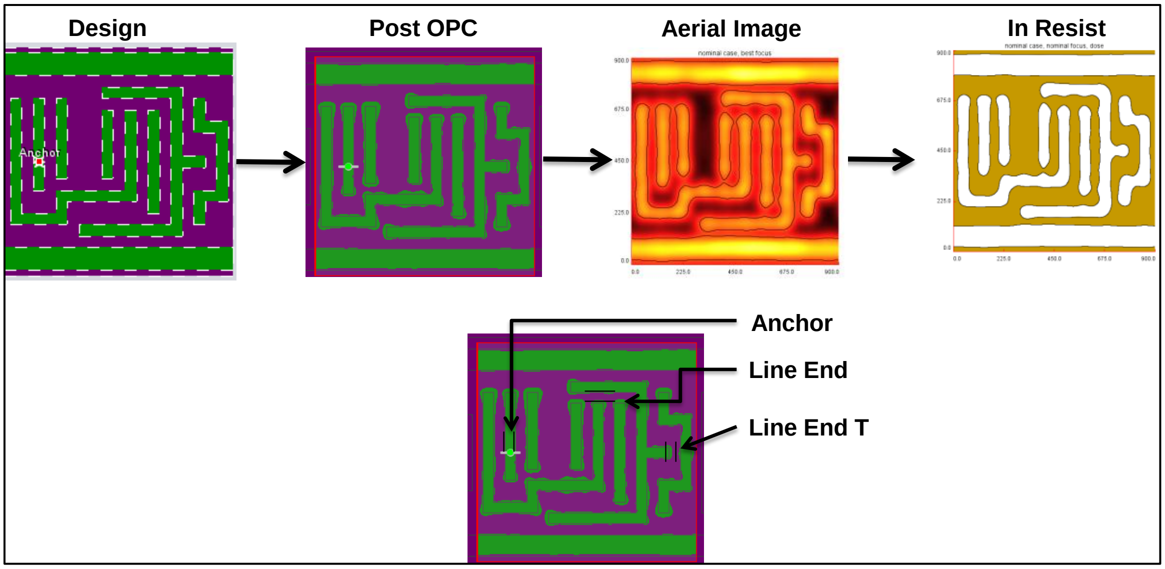

Figure 2: Test site for a metal layer at 90nm pitch

3.3 Variability Window Determination

The Variability Window as discussed in section 3.1 was determined for the anchor structure in figure 3. The Bossung plot shown with the drawn circle represents the "window" for this location in the design based on the dose / focus variation for scanners that support this node. The E95 bandwidth range is 300fm (+75/-25fm, baseline), the Authors choose this range since it is the current specification for this controller technology. The dose control of +/-0.45% and focus range of +/-14nm was investigated. The amount of CD (critical dimension) variation is 3.2nm at best dose and focus.

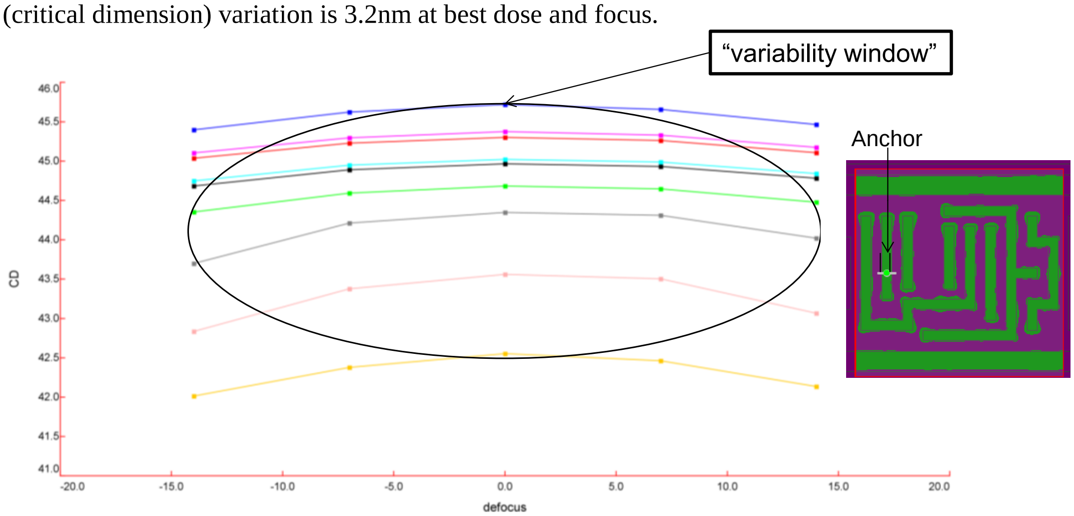

Figure 3: Bossung plot of "Anchor" structure & "Variability Window" based on existing scanner dose / focus variation

3.4 Variability Window at Best Dose through Existing Scanner Dose / Focus Variation

The Variability Window in figure 4 was determined for using the E95 bandwidth range of 300fm (+75/-25fm, baseline), dose to size only and a focus range of +/-14nm. The amount of CD (critical dimension) variation is 1.83nm at best dose and focus.

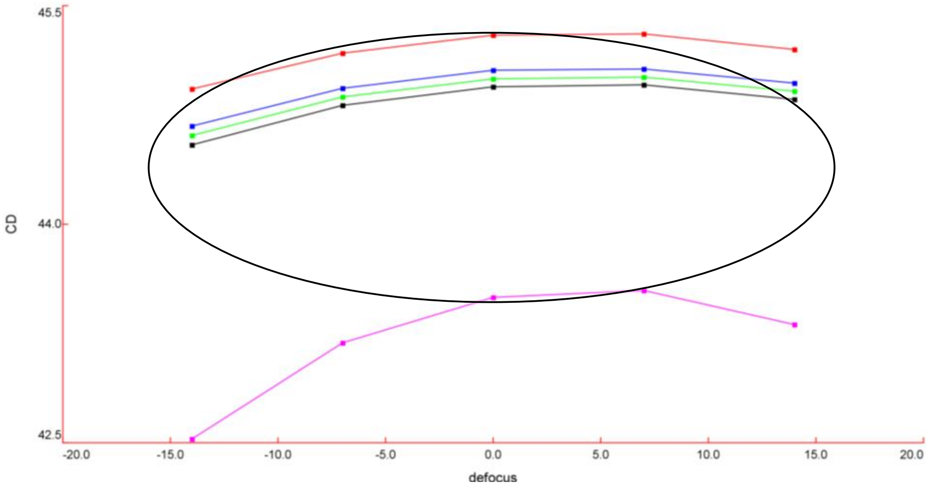

Figure 4: Bossung plot "Anchor" structure & "Variability Window" based on existing scanner dose / focus variation

3.5 Variability Window with DynaPulse bandwidth control

The Variability Window in figure 5 was determined for using the E95 bandwidth range of 300fm (+5/-5fm, baseline), dose to size only and a focus range of +/-14nm. The amount of CD (critical dimension) variation is 0.11nm at best dose and focus.

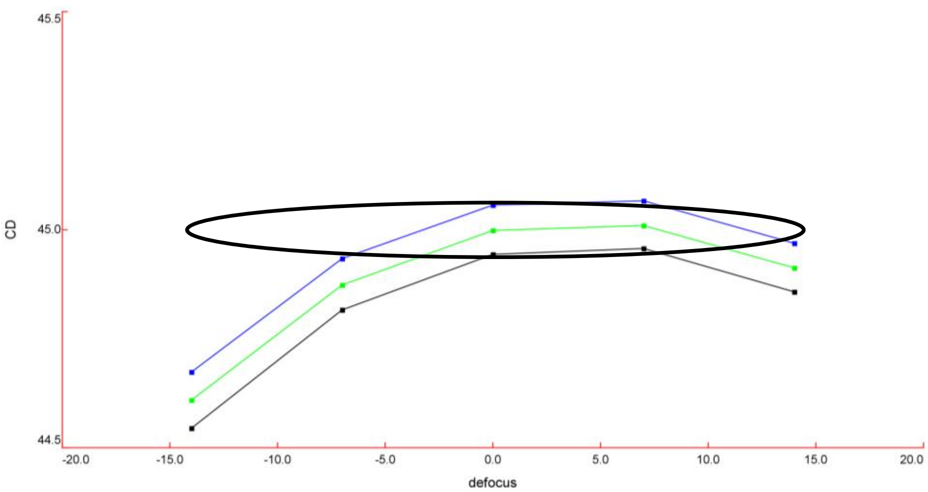

Figure 5: Bossung plot of "Anchor" structure & "Variability Window" single dose – DynaPulse bandwidth conditions

3.6 Variability Window and Test Site Summary

As discussed in previous sections, the dose / focus variation conditions are +/-0.45% for dose and +/-14nm for focus. The Authors would like to focus on the impact that improve bandwidth control has on CD variation from the Baseline controller to DynaPulse. The 3 areas of analysis from the test layout shown in section 3.2 are quantified in figure 6. The Authors plotted the baseline, baseline at fixed dose and DynaPulse at fixed dose. The purpose is to demonstrate that dose variation as expected, has an impact on CD variation, which is these test cases, is about 2x. Additionally, plotting Baseline fixed dose to DynaPulse fixed dose demonstrates even greater CD variation reduction which is about 7x-10x. However, not all structures are focus or bandwidth sensitive. In this case, the Line End structure is much more dose than focus sensitive as demonstrated in the plot below. As discussed in section 3.1 the Authors have made a number of assumptions and the intention of this study is to demonstrate a methodology and a trend. From this we see that these significant improvements in bandwidth control can impact CD variation.

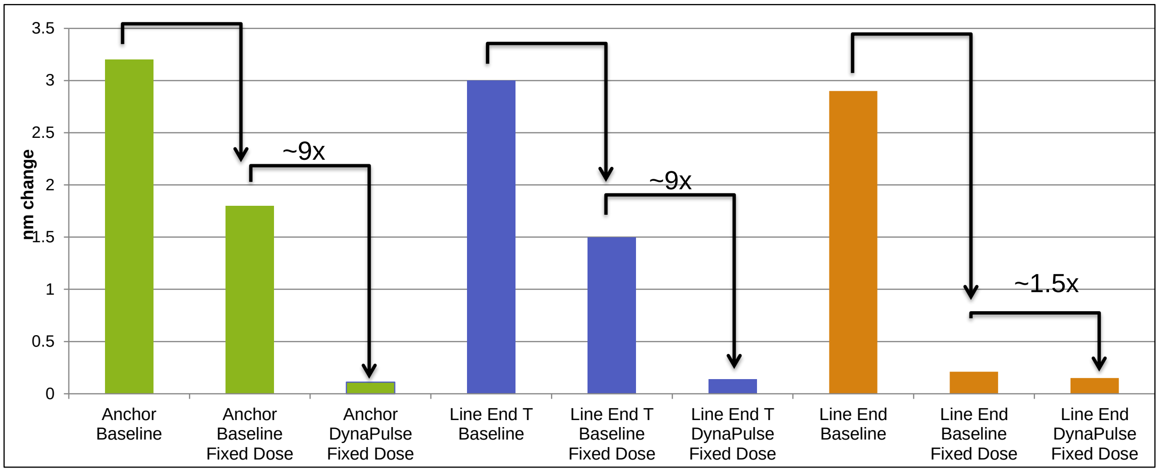

Figure 6: Bossung plot of "Anchor" structure & "Variability Window"

4 LOGIC CUSTOMER TEST CASE

A 28nm logic metal layer test case provided by a Customer, was used to determine the impact of bandwidth variation. This test case is of particular interest and is considered a hotspot during post OPC checking. Continuing our study, simulations are performed with HyperLith 7 from Panoramic Technologies. The imaging conditions have been provided by the Customer and consist of a custom illumination at 1.35NA. As in the Methodology study in section 3.1, no aberrations or Jones matrix was included. The non-OPC file was provided to determine correct CD requirements and the OPC'd mask file was provided for imaging studies. The OPC'd GDS, mask and in resist simulation is shown in figure 7. The mask is based on OMOG technology and imaging is calculated using Kirchoff's approximation in a 2μm x 2μm window. An LPM positive resist model was used with a simple calibration to existing 45nm line and space imaging. The bandwidth variation for this study is 300fm (+75/-25fm -baseline condition) and 300fm (+/-5fm – DynaPulse condition). Dose variation of +/- 0.5% and a focus variation of +/-14nm were used based on existing known scanner specifications.

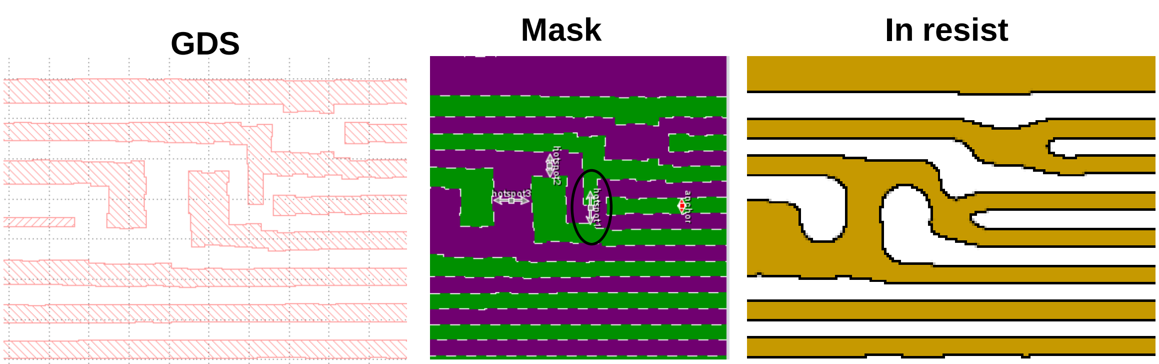

Figure 7: The OPC'd GDS, mask and in resist simulation. The HotSpot of interest is circled on the mask picture

4.1 Test Case Baseline with Scanner Dose / Focus variations

The Variability Window as discussed in section 3.1 was determined for the hotspot in figure 8. The Authors have plotted the Bossung data with a circle drawn to represent the "window" for this location once again based on the Scanner dose / variation specification for scanners that support this node. The E95 bandwidth range is 300fm (+75/-25fm, baseline), dose control of +/-0.45% and focus range of +/-14nm. The amount of CD (critical dimension) variation is 3.2nm at best dose and focus.

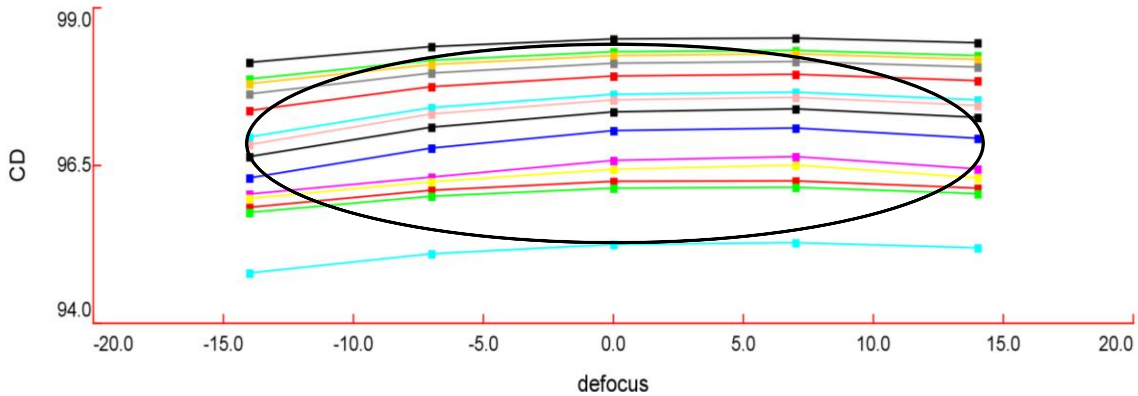

Figure 8: Bossung plot of "HotSpot" structure & "Variability Window" based on existing scanner dose / focus variation

4.2 Test Case with Baseline-fixed dose

The Variability Window in figure 9 was determined for using the E95 bandwidth range of 300fm (+75/-25fm, baseline), dose to size only and a focus range of +/-14nm. The amount of CD (critical dimension) variation is 1.78nm at best dose and focus. This decrease is expected and shown to demonstrate the impact of CD variation from dose.

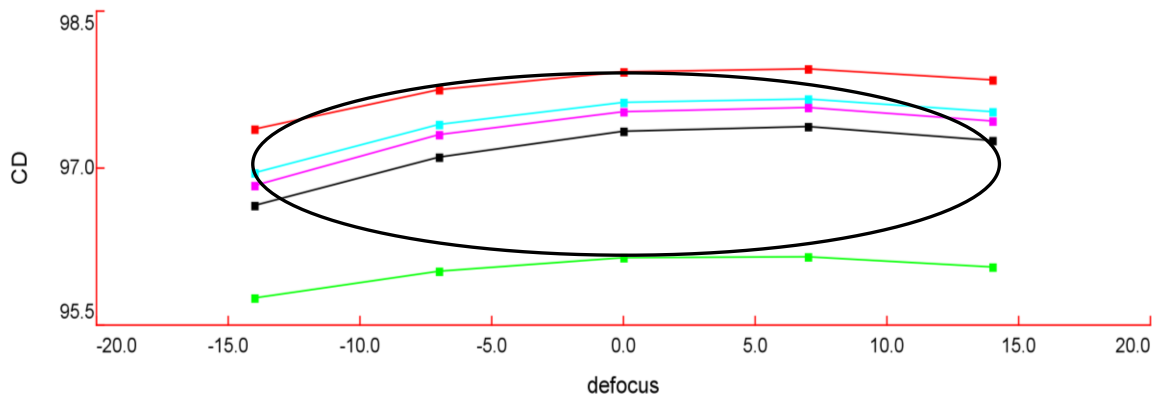

Figure 9: Bossung plot "HotSpot" structure & "Variability Window" single dose ATP conditions

4.3 Test case with DynaPulse-fixed dose

The Variability Window in figure 10 was determined using the E95 bandwidth range of 300fm (+5/-5fm, baseline), dose to size only and a focus range of +/-14nm. The amount of CD (critical dimension) variation is 0.27nm at best dose and focus.

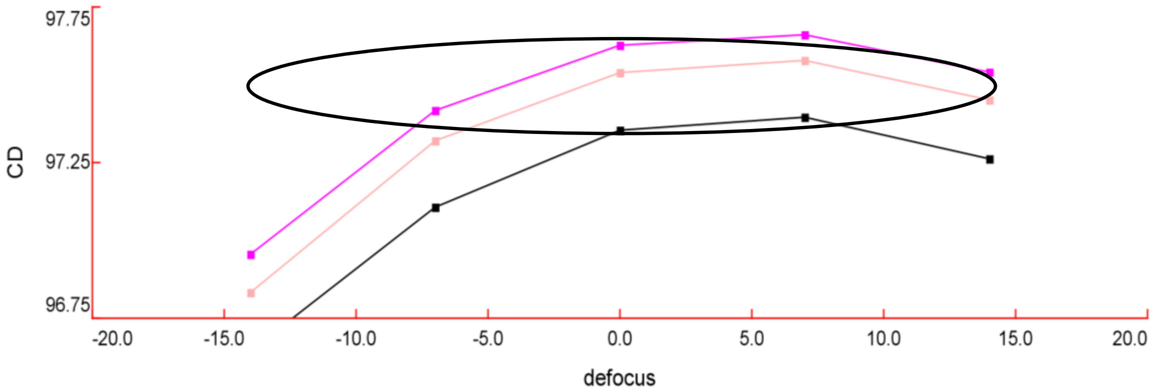

Figure 10: Bossung plot of "HotSpot" structure & "Variability Window" single dose – DynaPulse bandwidth conditions

4.4 Test Case Summary

Eliminating bandwidth variability directly effects CD variation. Figure 10 demonstrates that dose variation as expected, has an impact on CD variation which is this test case is about 2x. Further analysis demonstrates that an over 6x reduction was realized from the Baseline to DynaPulse bandwidth controller once dose variability is removed.

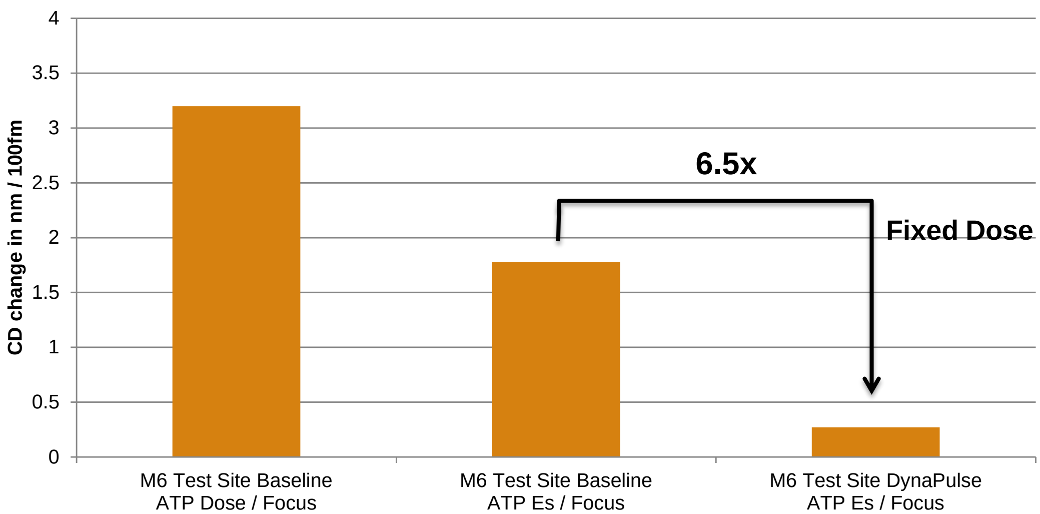

Figure 10. Hot Spot Process Window Results

4.5 On Wafer Test Case

On wafer imaging, experiments have been conducted through pitch and through bandwidth for line & space pairing. A line and space test reticle was used for wafers process on BARC coated silicon wafers using 115nm of JSR AIM positive tone photoresist. Wafers are exposed with quadrupole illumination at a numerical aperture of 1.35 and an outer sigma of 0.94 and inner sigma of 0.79 on an ASML NXT 1950i immersion ArF scanner. Figure 11a on the left, is data collected for a 40nm line on a 96nm pitch for a fixed dose and focus from 300fm to 380fm. The delta CD through bandwidth is plotted demonstrating a 2.1nm difference over the bandwidth range. Figure 11 on the right, is the CD variation range across the wafer for bandwidths ranging from 300fm to 380fm vs pitch. The CD range varies from just 1nm across the wafer to nearly 5nm's. This demonstrates that certain pitches can be sensitive to bandwidth changes depending on illumination and OPC robustness.

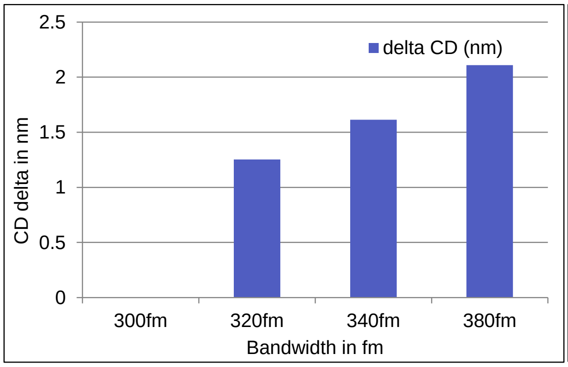

Figure 11a:
CD delta vs. bandwidth for fixed pitch.

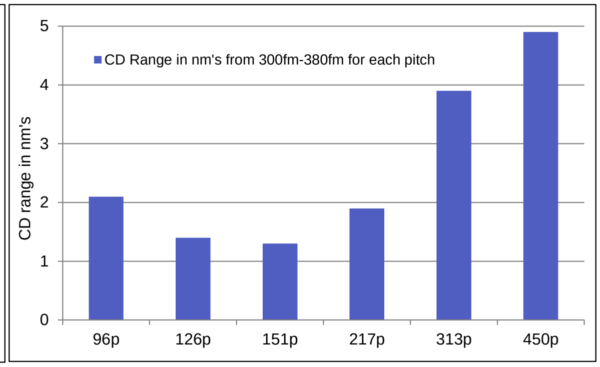

Figure 11b:
CD range across the wafer for bandwidths range of 300-380fm vs pitch.

5. CONCLUSIONS

The Authors have demonstrated a methodology for the quantification of the "variability window" for known scanner dose and focus variations along with known bandwidth variations in current ArF light sources. The bandwidth range from 275fm to 375fm was investigated for a Customer test site demonstrating reduction in CD variation when further reductions in bandwidth variation are applied. A 5x to 7x reduction in CD variation has been realized depending on the location within the design with certain hotspots demonstrating improvements and the potential to improve yield and CD uniformity. On wafer CD variation through bandwidth was demonstrated along with CD variation across the wafer vs. bandwidth vs. pitch has also been demonstrated.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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